DOI 10.26724/2079-8334-2022-4-82-192-196
UDC 616-001.45

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TRANSLATIONAL STUDY OF GUNSHOT INJURY TO THE COLON BY MODERN TYPES OF BULLETS

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Gunshot injuries to the colon are frequent in combat casualties, including the current invasion of Russia into Ukraine. Colon wounds are associated with high mortality and severe purulent-septic complications. In this translational study, we investigated gunshot wounds to the colon in 374 servicemen who were injured in East Ukraine. In the experimental part, a special certified ballistic gel 10 % FBI Ballistic Block was used for ballistic analyses of various bullets to confirm clinical data. Data analyses showed that the severity of colon injuries depended on the type of wounding projectile, which was confirmed in gel experiments. The action of the wounding projectile bullet "V-Max" 5.45x39 mm (with expansive properties) showed significant differences in relation to the colon injury as compared to the usual all-shell claw "PS" ($p<0.05$). Hollow-point bullet wounds require different surgical tactics as opposed to full-shell bullet wounds.

Key words: gunshot wound, colon injuries, combat injury, hollow-point bullet, ballistic gel.

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ТРАНСЛЯЦІЙНЕ ДОСЛІДЖЕННЯ ВОГНЕПАЛЬНОГО ПОРАНЕННЯ ТОВСТОЇ КИШКИ СУЧАСНИМИ ВИДАМИ КУЛЬ

Вогнепальні поранення товстої кишки є частими при бойових втратах, включно з сучасним вторгненням Росії в Україну. Поранення товстої кишки пов'язані з високою летальністю та важкими гнійно-септичними ускладненнями. У цьому трансляційному дослідженні ми досліджували вогнепальні поранення товстої кишки у 374 військовослужбовців, які отримали поранення на сході України. В експериментальній частині для балістичного аналізу різних куль для підтвердження клінічних даних використовувався спеціальний сертифікований балістичний гель 10% FBI Ballistic Block. Аналіз даних показав, що тяжкість ушкоджень товстої кишки залежала від типу ранючого снаряда, що було підтверджено в експериментах з гелем. Дія ранючої снарядної кулі «V-Max» 5,45х39 мм, що має розширювальні властивості, в ураженій черевній порожнині з пошкодженням товстої кишки має достовірні відмінності ($p<0,05$) від звичайної суцільногільзової кульшової «ПС». Порожнисті кульові поранення вимагають іншої хірургічної тактики на відміну від повних кульових поранень.

Ключові слова: вогнепальне поранення, поранення товстої кишки, бойове травмування, порожниста куля, балістичний гель.

The study is a fragment of the research project "Development of the medical care system based on the experience of implementing measures to ensure national security and defence, repel and deter armed aggression of the Russian Federation", state registration No. 0120U101456.

Mortality among wounded to the abdomen is high [8]. The frequency of injuries to some abdominal organs, including colon injuries, is increasing as judged from the known wars and armed conflicts: World War II – 28.0 %, Korean War – 31.5 %, Vietnam War – 15.8-26.5 %, Arab-Israeli war – 37.2–41.0 %, US surgical centers 15.3–41.6 %, ATO/OOC in Ukraine – 26.2 %. Injuries to the colon in the structure of combat injuries of the abdomen account for up to 43.0% with penetrating wounds, constituting the second place in frequency after damage to the small intestine [4]. Most colon injuries are associated with penetration, with a most frequent injury to the ascending and transverse colons [1, 3]. It is a high demand to investigate the ballistic features and combat trauma, considering the permanent aggression of Russia against Ukraine since 2014 in a hybrid manner, and since February 2022 as a full invasion [6, 14].

With a combat injury to the abdomen, the incidence of postoperative complications is 54.0-81.0 %. Mortality is 12.0–31.0 % [4, 9, 12], and according to other data (9, 10) in recent military conflicts with damage to the colon, it reaches 65.0%, remains high and is associated with severe purulent-septic complications.

The purpose of the study was to investigate and evaluate both clinical and morphological features of the gunshot wounds of the abdomen with injuries to the colon by whole-shell balls and semi-shell balls with expansive properties.

Materials and methods. Clinical cases of gunshot wounds to the abdomen in 374 servicemen with injuries to the colon were studied, with a follow-up period from 2014 to 2020 during the fighting in East Ukraine. In 262 (70.1 %) cases there were gunshot shrapnel wounds, in 112 (29.9 %) cases there were gunshot bullet wounds included in the study. The average age of these wounded was 21.3±3.7 years. They were taken to advanced nursing brigades and to the second level of care in military-mobile hospitals. For diagnostic and therapeutic purposes, the staff complex of laboratory and instrumental research of the second level was used. All the wounded were admitted in a state of shock of various stages and were placed in the intensive care unit, where they underwent measures of anti-shock therapy with diagnostic tests. All wounded were operated, the size of the inlet and outlet was determined, the Colon injury scale was used to assess the nature of colon damage, and the presence of foreign metal bodies – bullets, signs of fragmentation, number of fragments and deformation were assessed by radiological signs of the abdominal cavity [9].

In the experimental part as a ballistic material, used a special certified ballistic gel 10 % FBI Ballistic Block made in the USA.

The 10 blocks of ballistic gel were used, in which one shot was fired with different cartridges with full-shell bullets such as Full Metal Jacketed (FMJ) “PS” 5.45x39 mm, with a steel core (7H6), and cartridges of the same caliber 5.45x39 mm, equipped with expansive bullets such as Jacketed Soft Point (JSP) type “V-Max”. The experimental part was performed in line with previously described protocols [11, 12, 15].

Shots were fired from AKS-74 automatic firearms from a distance of 100 meters. The experiments were performed under normal environmental conditions (temperature 25^0C, relative humidity 72 %, atmospheric pressure 738 mm Hg/h). After the shots, planimetric studies of the wound canal in a ballistic gel were performed, and the presence of additional radial gaps was visualized as a manifestation of the effect of the temporarily pulsating cavity. The Wound Profile method (WP) measured the length of two maximum gaps to estimate the radius of the temporarily pulsating cavity, which is equal to: r tp = (r max1+r max2)/2.

Statistical analysis of the results of the study was performed using the methods of non-parametric statistics according to our previous experience. We evaluated the frequency characteristics of indicators for qualitative parameters (P) and averages for quantitative data (arithmetic mean – M) with an estimate of their variability (standard deviation – σ). The average error of the studied indicators (m) was also determined with an estimate of the confidence interval. Mathematical processing of the obtained results was performed using the Student's t-test. The difference between the mean values of the studied trait in the main and the observation group was accepted if the p-level of the relevant statistics was less than 0.05. Empirical values of statistics were calculated using the Statistica 12.0 software package. The received data were processed using Microsoft Excel 2016 software.

Results of the study and their discussion. Among 112 gunshot wounds in 69 (61.6 %) cases there were injuries from a full-shell bullet, in 43 (38.4 %) – a bullet with expansive properties.

According to the results of a clinical study in 69 (61.6 %) cases of COC injuries, the size of the fire inlet on the anterior abdominal wall was 0.5±1.2 cm. In 43 (38.4%) wounded EC, the corresponding size was 4.5±2.3 cm ($p<0.05$).

The presence of a penetrating wound of the abdomen was diagnosed in 55 (49.1 %) wounded, the size of the outlet was 4.2±3.5 cm.

57 (50.9 %) of the wounded were diagnosed with signs of blind injury. According to the results of X-ray examination of the abdominal cavity, 14 (24.6 %) wounded were diagnosed with a foreign body – a whole ball. In 43 (75.4 %) there were signs of deformation of the ball, and a variety of multiple foreign metal fragments of 5 or more, different sizes, which was a sign of fragmentation of the ball directly in the abdominal cavity.

During the operation, damage to the colon was found in all 112 wounded. It should be noted that the largest number were wounded with II degree – 54 (48.2 %), where the wall rupture was up to 50 % of the circle, I degree – 28 (25 %), with contusion and hematomas of the wall, signs of partial rupture, but without perforation, and the most severe were injuries with IV and V degree of damage, respectively – 9 (8.0 %) and 3 (2.7 %) wounded (Table 1).

Table 1

The degree of damage to the colon on the scale Colon injury scale

Degrees	Description of damage	Amount	%
I	Contusion or hematoma without devascularization, partial rupture, no perforation	28	25 %
II	Wall rupture up to 50 % of the circumference	54	48.3 %
III	Wall rupture over 50 % of the circle without intersection	18	16 %
IV	Transverse rupture of the colon	9	8.0%
V	Transverse rupture with segmental tissue loss, devascularized segment	3	2.7 %
Total		112	100 %

Analyses of the topographic and anatomical localization of wounds showed the following results for the gunshot wounds of the colon with a full-shell bullet (n=69) *vs.* gunshot wounds of the colon by an expansive bullet (n=43), respectively: caecum 6 (8.7 %) *vs.* 2 (4.6 %); ascending colon 9 (13.1 %) *vs.* 9 (21 %); colon hepatic angle 3 (4.4%) *vs.* 4 (9.3 %); transverse colon 10 (14.5 %) *vs.* 7 (16.2 %); colon spleen angle 5 (7.2 %) *vs.* 1 (2.3 %); Descending colon 21 (30.4 %) *vs.* 12 (28 %); sigmoid colon 15 (21.7 %) *vs.* 8 (18.6 %).

Clinical cases of gunshot wounds of the colon are presented in Fig. 1.

In the wounded in the abdomen with damage to the colon, through and blind types of abdominal injuries were observed, with the presence of a solid bullet in the abdominal cavity and its deformation (Fig. 2), or fragmentation in the form of multiple metal fragments.

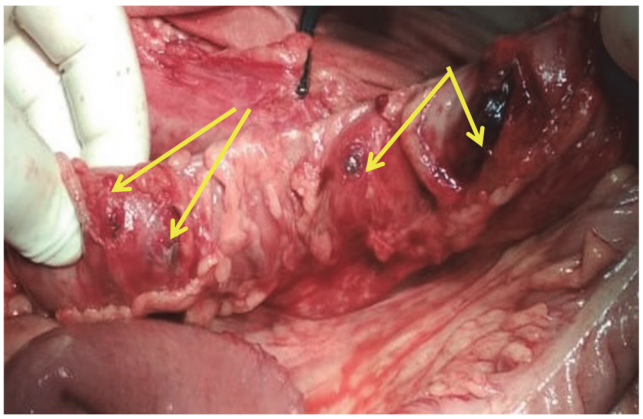

Fig. 1. Gunshot wound to the abdomen with multiple injuries of the colon (II-III degree of damage).

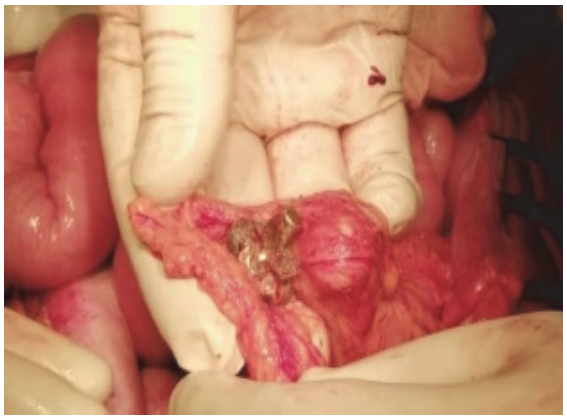

Fig. 2. View of a deformed bullet in the abdominal cavity with a mushrooming effect

The length of the wound channel in the ballistic gel when fired with FMJ “PS” was 30.5±1.7 cm, when fired with JSP “V-Max” – 24.8±1.5 cm (Fig. 3).

A study in a laser green beam made it possible to clearly diagnose the course of the wound channel and radial breaks in the ballistic gel; they radically differed both in size, shape and their number. In a ballistic gel with a “PS” bullet pierced in a green laser beam with multiple radial breaks, radial breaks were found only around the residual cavity in an amount of up to 10, they were small in size – 0.8±0.5 cm.
When examining the wound canal after being shot with an expansive bullet “V-Max”, it was found that the shape was different spindle-shaped (Fig. 4), the size was larger – 1.8±1.5 cm.

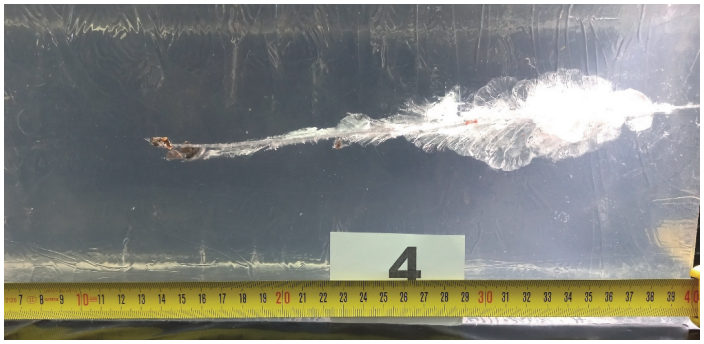

Fig.3. Illustration of the ballistic gel with a shot of JSP “V-Max”.

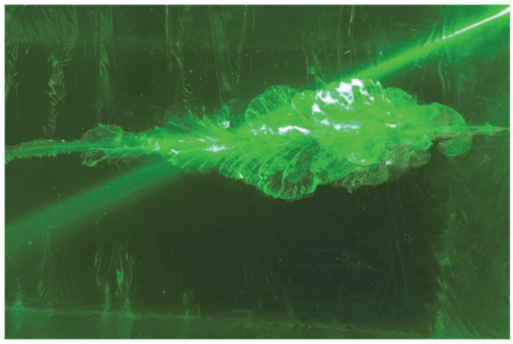

Fig. 4. The shape of the wound canal in a ballistic gel with a shot of an expansive bullet “V-Max”, in a green laser beam with multiple radial gaps.

The study of the shape of radial gaps in the frontal plane allowed us to calculate the length of the two maximum gaps when firing an expansive bullet "V-Max", which were 1.4 and 1.5 cm, respectively. The radius of the temporarily pulsating cavity for the FMJ "PS" was 1.4±0.8 cm, for the bullet "V-Max", respectively – 2.25±1.3 cm.

The experiment allowed us to study the properties of these balls on a ballistic gel as a simulator of biological tissues, where the length of the wound canal was significantly shorter when firing an expansive bullet, compared to a conventional full-shell bullet as shown in Table 2.

Table 2

Parameters of the wound canal in ballistic gel as a simulator of biological tissues

Parameters	FMJ "PS" 5,45x39 мм, n=10	JSP "V-Max" 5,45x39 мм, n=10
Wound length channel, cm	30.5±1.7	24.8±1,5
The number of radial breaks	≤10	≤100
Dimensions of radial breaks, cm	0.8±0.5	1,8±1,5
Radius of the temporarily pulsating cavity, cm	1.4±0.8	2.25±1.3
Wound form channel	Conical	Fusiform

Results from this translational study to indicate that different types of bullets have their own specific signs of injury to the abdomen and specifically to the colon [14]. These signs are important because they determine the scope and tactics of surgery. Our results are in line with other studies, showing the possibility of determining which wound projectile caused the injury by the size of the inlet and outlet gunshot holes, perforated or penetrated abdominal gunshot wound, the judgement of radiographical data from the abdominal cavity, the presence of a solid ball, or its deformation, fragmentation [1]. In this study, we showed that colon injuries were presented as grade II or higher (by Colon injury scale) in the case of the wound by an expansive bullet due to its fragmentation and deformation, which was subsequently confirmed by ballistics experiments in this study as well as confirmed by analyses of other reports [11, 12, 15]. We have also performed analyses of the relation between the volume of surgical operation and the kind of projectile. Our basic research data in ballistic gel confirmed clinical findings, indicating similar energy features in the gel and in the biological tissue, which is in line with other clinical studies showing severe colon injury in penetrating gunshot wounds [2]. The presence of a blind wound by such bullets causes the transfer of all kinetic energy into the abdominal cavity, leading to severe complications in the postoperative period. Similar to other studies, we also noticed that the abovementioned changes were not observed in case of gunshot injury by the ordinary bullet (*i.e.,* having perforating wound) [3, 4].

A higher frequency of multiple perforations of the colon was found in the patients after the injury by the expansive bullets, which is confirmed by the results from our previous experimental studies as well as confirmed by others [2, 14].

The shape of the wound canal clearly defined the differences; where for an expansive bullet its size was larger, and the shape was fusiform, against a full-shell bullet, where the shape was conical, and its size was smaller [7, 13]. Our experimental finding showed that radial ruptures of the colon were of great clinical importance, as these features could be a sign of the influence of the temporary pulsating cavity and its wavy oscillations at different distances from the wound canal, as well as reflecting the distribution of kinetic energy scattered by the wound projectile in the simulator, which also was seen in other studies [13]. Radial ruptures of the colon wall in the postoperative period can cause complications in the form of microperforations, erosive bleeding, failure of anastomoses due to microthrombosis and hypoxia in these areas as shown in our early reports and in other publications [9, 14]. Still, the complete pathogeneses of the abovementioned changes are not fully understood, and further research should be performed in that direction. It is also worth mentioning that the radius of the temporarily pulsating cavity was larger under the action of an expansive bullet, which indicates a greater force of transmitted kinetic energy and, accordingly, greater pressure in the temporarily pulsating cavity, which determines its size, which was also shown in other studies of ballistic gel [11]. In our opinion, measurements of the length of the two maximum gaps also reliably indicated a larger radius of the temporary pulsating cavity under the action of the bullet with expansive properties, compared to the usual one, where such radius was smaller, which is confirmed by other studies using ballistic gels [11].

Conclusion

To sum up, the action of the wounding projectile bullet "V-Max" 5.45x39 mm, with expansive properties in the wounded abdomen with damage to the colon has significant differences ($p<0.05$) from the usual full-shell bullet "PS" 5.45x39 mm, in the size of the entrance hole – which is significantly larger, the presence of blind injury, radiological signs of deformation and fragmentation of bullets with multiple nature of damage to the colon on the scale of Colon injury scale from II to V degree. The size of the wound canal, its shape and the presence of radial ruptures with the determination of the length of the two maximum ruptures indicate that the radius of the temporarily pulsating cavity is significantly larger (2.25±1.3 cm) due to the transfer of all kinetic energy inside the object of damage, which causes more massive destruction of organs and tissues of the abdomen. Expansion bullet wounds require different surgical tactics as opposed to bulletproof bullet wounds. Studies of the impact of radial ruptures on complications in the postoperative period require further research.

References

1. Biffl WL, Moore EE, Feliciano DV, Albrecht RM, Croce MA, Karmy-Jones R, et al. Management of colorectal injuries: A Western Trauma Association critical decisions algorithm. J Trauma Acute Care Surg. 2018;85(5):1016-20. DOI: 10.1097/TA.0000000000001929

2. Cardi M, Ibrahim K, Alizai SW, Mohammad H, Garatti M, Rainone A, et al. Injury patterns and causes of death in 953 patients with penetrating abdominal war wounds in a civilian independent non-governmental organization hospital in Lashkargah, Afghanistan. World J Emerg Surg. 2019;14:51. DOI: 10.1186/s13017-019-0272-z

3. Cullinane DC, Jawa RS, Como JJ, Moore AE, Morris DS, Cheriyan J, et al. Management of penetrating intraperitoneal colon injuries: A meta-analysis and practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg. 2019;86(3):505–15. DOI: 10.1097/TA.0000000000002146

4. Elfaedy O, Elgazwi K, Alsharif J, Mansor S. Gunshot wounds to the colon: predictive risk factors for the development of postoperative complications, an experience of 172 cases in 4 years. ANZ J Surg. 2020;90(4):486–90. DOI: 10.1111/ans.15575

5. Feliciano DV. Abdominal Trauma Revisited. Am Surg. 2017;83(11):1193–202.

6. Gybalo RV, Lurin IA, Safonov V, Dudla DI, Oklei DV, Dinets A. Retained bullet in the neck after gunshot wounds to the chest and arm in combat patient injured in the war in Ukraine: A case report. Int J Surg Case Rep. 2022;99:107658. DOI: 10.1016/j.ijscr.2022.107658

7. Hakki L, Smith A, Babin J, Hunt J, Duchesne J, Greiffenstein P. Effects of a fragmenting handgun bullet: Considerations for trauma care providers. Injury. 2019;50(5):1143–6. DOI: 10.1016/j.injury.2019.01.033

8. Herasymenko O, Yenin R, Shepitko K, Herasymenko S. Optimization of diagnostic abdominal gunshot wounds in combat conditions. World of Medicine and Biology. 2019;15(67):038–42. DOI: 10.26724/2079-8334-2019-1-67-38

9. Jinescu G, Lica I, Beuran M. Traumatic colon injuries -- factors that influence surgical management. Chirurgia (Bucur). 2013;108(5):652–8.

10. Johnston LR, Bradley MJ, Rodriguez CJ, Mcnally MP, Elster EA, Duncan JE. Ostomy Usage for Colorectal Trauma in Combat Casualties. World J Surg. 2019;43(1):169–74. DOI: 10.1007/s00268-018-4759-7

11. Kerkhoff W, Visser M, Mattijssen EJAT, Hermsen R, Alberink IB. A combined cowhide/gelatine soft tissue simulant for ballistic studies. Forensic Sci Int. 2022;338:111392. DOI: 10.1016/j.forsciint.2022.111392

12. Limón E, Shaw E, Badia JM, Piriz M, Escofet R, Gudiol F, et al. Post-discharge surgical site infections after uncomplicated elective colorectal surgery: impact and risk factors. The experience of the VINCat Program. J Hosp Infect. 2014;86(2):127–32. DOI: 10.1016/j.jhin.2013.11.004

13. Mo GL, Liu J, Ma QW, Jin YX, Yan WM. Influence of impact velocity and impact attack angle of bullets on damage of human tissue surrogate -- ballistic gelatin. Chin J Traumatol. 2022;25(4):209–17. DOI: 10.1016/j.cjtee.2022.03.004

14. Tsymbalyuk VI, Lurin IA, Chaikovskyi YB, Graboviy OM, Gumenyuk KV, Nehoduiko VV, et al. Comparative evaluation of histological results of modern fire inflammatory injuries of the column by different types of bullets in the experiment. World of Medicine and Biology. 2022;1(79):244–78. DOI: 10.26724/2079-8334-2022-1-79-244-248

15. Wen Y, Xu C, Jin Y, Batra RC. Rifle bullet penetration into ballistic gelatin. J Mech Behav Biomed Mater. 2017;67:40–50. DOI: 10.1016/j.jmbbm.2016.11.021

Стаття надійшла 13.10.2021 р.